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Using Weather Sensitivity to Forecast Thailand's Electricity Demand

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Abstract - As part of a study into the potential impact of climate change on Thailand's electricity demand it has been necessary to find an efficient and effective way of linking climate to demand levels whilst minimising data requirements. The paper sets out a multiple linear regression approach to modelling the influence of temperature on demand by representing demand as hourly time-slices for each month across the year. The application of the models in determining the impact of uniform rises in temperature are presented along with a preliminary exploration of what such sensitivity means in terms of Thailand's demand levels in the second quarter of the century.

Keywords - weather sensitivity, electricity demand, Thailand.

1 INTRODUCTION

The growth in electricity demand in Thailand and other Asian economies is being driven primarily by increases in Gross Domestic Production (GDP) and population. It has been estimated that the high demand growth will continue into the medium term at least with annual increases of 5% to 8% up to 2016 [1]. It is anticipated that this and longer-term growth will be affected by the changes in weather patterns brought about by climate change; recent record weather [2] would appear to support this postulation.

Thailand's electricity demand is very much influenced by the seasons (summer, monsoon and winter). Typically summer demand exceeds that of winter by approximately 4500 MW [3]. This seasonality can be seen clearly in Figure 1 which shows the mean daily demand profiles for each of the months in 2004. The differences are, to a significant degree, related to temperature with the hotter temperatures in summer meaning that people spend more time indoors increasing in-house demand (air-conditioning and refrigeration). Prevailing precipitation, humidity, wind-speed and cloud cover also play a role in determining demand.

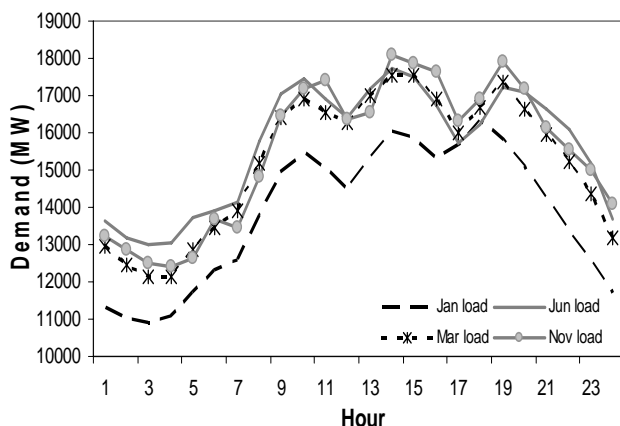


Figure 1. Daily demand profiles in Thailand for 2004 [4]

The work presented here forms part of an investigation into the potential for climate change to influence electricity demand in Thailand. As reported previously [5],[6], the work is aiming to model the changes in daily and monthly demand profiles over the long term horizon during which the climate is expected to change. The purpose of this paper is to highlight the development of a series of models that allow weather-dependant demand to be projected.

The paper is organised as follows: the next section looks at weather-sensitive modelling of demand and Section 3 sets out an example of their application in the ongoing research project.

2 MODELLING WEATHER SENSITIVITY

The broader research required a means of translating future projections of climate into demand. The requirement was for a model or models that allowed anticipated changes in mean, maximum and minimum temperature (and potentially other climate variables) to be used to indicate future changes in daily and seasonal load profiles with particular interest in peak demand levels.

One option was to construct detailed bottom-up demand models of each sector (domestic, commercial, industrial etc.) from demographic information as well as load characteristics like building construction, air-conditioning take-up and so on. Such an approach would potentially allow accurate weather-dependent demand projections to be made. The downside to this is the range of economic and other data required as well as the need for disaggregated weather and electricity demand information. This information is perhaps more readily available in an industrialized economy.

Given this as well as the fact that this study is of a preliminary nature a simpler approach was adopted that formulated regression models linking demand with temperature on a time-of-day and monthly basis. This approach is broadly similar to that reported in [7]. In making projections with such a model there is an implicit assumption that the relationships hold over time. However, the benefits of the simpler weather sensitivity model appear to offset this risk.

The data kindly made available by EGAT consisted of hourly demand for the whole of Thailand over the period 1996-2004. In addition, hourly weather information for the same period was sourced from a weather station in the Bangkok metropolitan area. As over 70% of Thailand's electricity is consumed in the Bangkok area this obvious simplification of the weather situation is believed to be a reasonable approximation.

The weather-sensitivity models are constructed by using multiple linear regression to encode the patterns in the daily electricity consumption over each month. A wide range of models were tested varying in terms of the variables they used (humidity etc) and the degree of temporal detail. The models that appeared to offer the most consistent and high quality regressions were based on cooling degree hours (CDH, derived from temperature) and hourly demand. To allow exploration of the impact of temperature on the daily load profile, one regression was performed for each hourly time-slice (e.g.

5 to 6pm) in each month. This gave 24 regressions for each month each of the form:

$$D = \beta_1 + \beta_{CDH} (CDH) + \varepsilon \quad (1)$$

where D is the demand in each time-slice (1 am to 12 am), β_1 is the intercept of the regression line on the demand axis, β_{CDH} is the slope of the regression line giving the sensitivity of demand to cooling degree hours (in MW/CDH) and ε is the random error.

The use of cooling degree hours (or degree days) is relatively common in demand modelling (e.g., [8], [9]) as it attempts to account for human comfort by defining a threshold temperature above which air-conditioning is required and below which it is not. As such temperature changes that serve to raise the temperature beyond the threshold will have the greatest impact on electricity demand. The cooling degree hour is given by:

$$CDH(T_h) = \begin{cases} \sum_{h=1}^N (T_h - T_{b_h}) & \text{for } T \geq T_b \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

where N is the number of cooling degree hours in the period of interest and T is the air temperature and T_b is the threshold temperature. In Thailand the threshold temperature is taken to be 24°C.

The results of using Equation (1) for 3 months that are broadly representative of the Thai seasons are shown in Figures 2 to 4 (March = summer, June = monsoon, November = winter). The actual and estimated demand over the average day in each month is presented along with a further trace depicting the sensitivity coefficient (β_{CDH}) which represents the relative sensitivity of each hour to changes in CDH acting as a proxy for temperature. The models indicate a reasonable fit with actual demand with mean absolute percentage errors (MAPE) of 1.86% for March (Figure 2), 0.93% for June and 2.60% for November. These are backed up by high coefficients of determination (R^2) of between 0.79 and 0.92.

In each case, the pattern of demand broadly reflects the temperature profile with demand starting to rise around 8am achieving a peak around 2pm before falling back until the evening load pickup. The relative sensitivity of demand to temperature level is consistent with the higher temperatures during the working day requiring cooling of workplaces and with an additional increase in sensitivity during the evening as people return home and require cooling to reduce the heat accumulated during the day

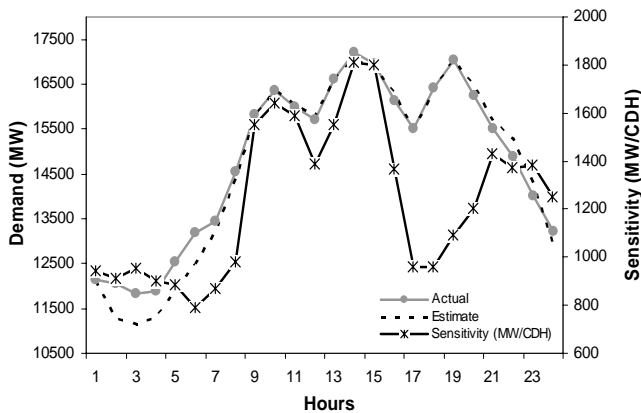


Figure 2. Actual and estimated demand and demand sensitivity in March 2004

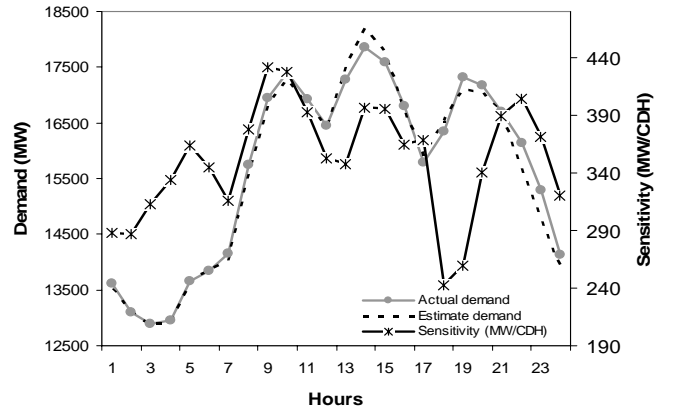


Figure 3. Actual and estimated demand and demand sensitivity in June 2004

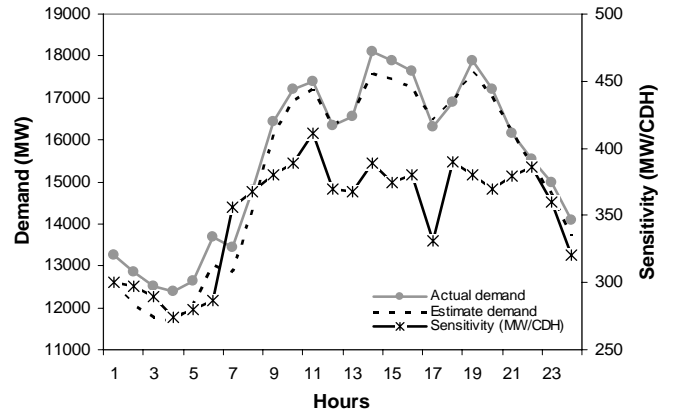


Figure 4. Actual and estimated demand and demand sensitivity in November 2004

What is apparent is that the peak sensitivity tends to coincide with the peak demand (around 2pm). This implies that temperature rises from climate change will have a proportionally greater impact on peak demand levels. Also apparent is that there is a relatively greater sensitivity during the summer months (Figure 2) than in the others; this is evidenced by the higher sensitivity coefficients.

3 APPLYING THE MODEL

This section briefly outlines the application of the weather-sensitive demand models to the task of projecting future demand under the influence of climate change. The example presented here shows the application of the models to the hypothetical cases of uniform warming of 1 or 2°C across the year. Clearly this is rather simplified as (1) temperature rise will vary throughout the year and (2) the diurnal temperature range will also alter suggesting non-uniform changes on a daily basis. However, for the purpose of illustrating their use it is adequate.

Figures 5 to 7 indicate the impact of raising temperatures by 1 and 2°C in each of the months presented. It can be seen that in all cases the demand level does rise as temperature increases. The impact on peak and mean demand levels for all three cases is summarised in Table 1.

March (summer) has the highest sensitivity coefficients and correspondingly sees the largest increase in demand as temperature rises. The range of increases across the hourly time-slices ranges from 5.9% to the peak value of 10.6%. Given the greater sensitivity, the increases at peak hours are greater than the mean change in demand. For example, for a temperature rise of 1°C demand

increases by 10.6% and 8.3% representing 1811 MW and 1226 MW, for peak and mean demand respectively. The increases associated with peak hours for June (monsoon) and November (winter) are far smaller at around 450 MW and 336 MW.

The demand increases with the 2°C are approximately double that for 1°C. It should be noted, however, that although the relationship between demand and CDH is linear it does not automatically follow that the demand increase seen with a 2°C rise is twice that of the 1°C case. This is because the threshold associated with the CDH calculation introduces a non-linearity. For example, an hour where the historic temperature is below 23°C would only add to the CDH count and therefore raise demand when a 2°C rise occurred, as with the 1°C rise the temperature would remain below the 24°C threshold. When this happens demand is increased by a proportionately greater amount.

	March	June	November
Peak demand +1°C	10.6%	2.5%	2.2%
Mean demand +1°C	8.3%	2.3%	2.7%
Peak demand +2°C	21.3%	4.5%	4.4%
Mean demand +2°C	16.7%	4.6%	5.4%

Table 1. Change in peak and mean demand with uniform rise in temperature

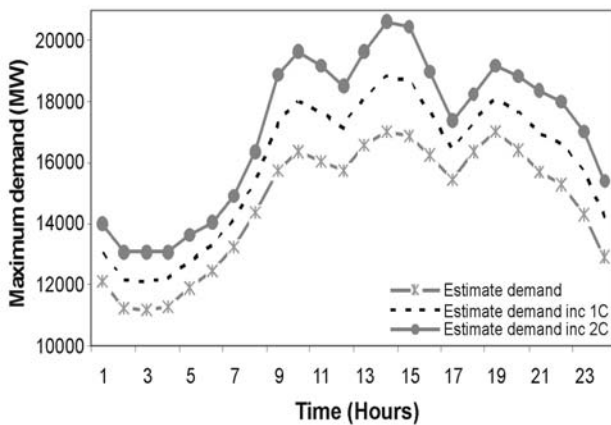


Figure 5. Modelled demand with temperature rise of 1 and 2°C in March

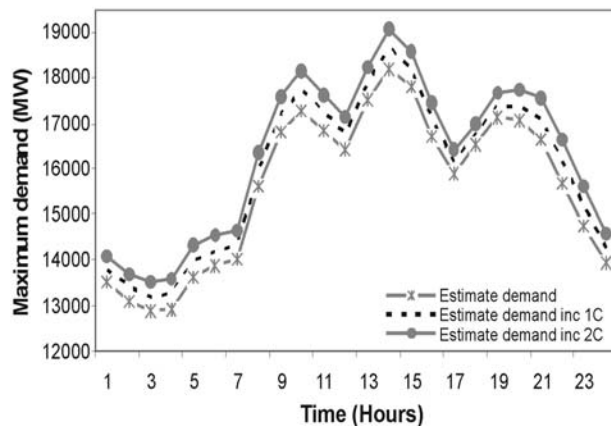


Figure 6. Modelled demand with temperature rise of 1 and 2°C in June

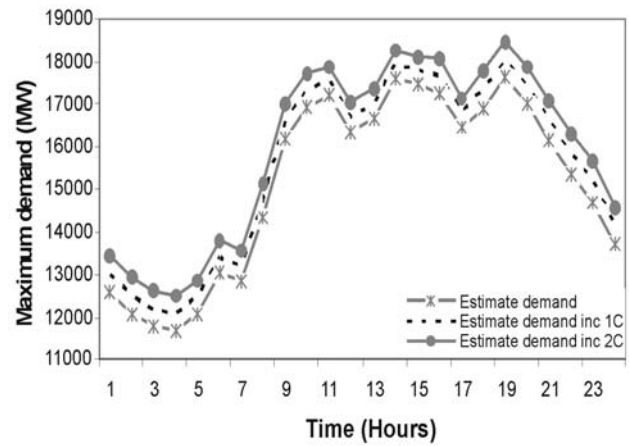


Figure 7. Modelled demand with temperature rise of 1 and 2°C in November

While the example shown here would be reasonable for demand in 2004, a particular difficulty arises with predicting the impact on the demand of the 2020s by when a temperature change of about 1 or 2°C would be expected to occur. As such a key part of the research is to provide forecasts of demand for the years up to 2050 for climate impact analysis.

Long term electricity demand growth is correlated with growth in GDP and population and the most common means of projecting future demand is via an auto-regressive model such as [10], [11]:

$$D_t = \beta_1 + \beta_2 (G_t - G_{t-1}) + \beta_3 (P_t - P_{t-1}) + \beta_4 (D_{t-1}) + \varepsilon \quad (3)$$

where G is GDP, P is population and the subscript t relates to the current year and $t-1$ to the previous year.

Such a model was developed from the dataset covering 1997-2005 based on peak monthly demand and quarterly GDP and population data linearly interpolated to a monthly base. The model was calibrated on data from 2001 to 2005 and validated on the previous 4 years. The performance of the model is shown in Table 2. The performance in the calibration period is very good but suffers when retrospectively applied to the earlier period. However, given that the earlier period includes that of the Asian economic crisis of 1998 its performance is reasonable.

Performance	Calibration 2001-2005	Validation 1997-2000	1997-2005
R ²	0.97	0.71	0.96
MAPE (%)	0.47	0.52	0.51
Mean error (MW/Month)	84	74	56

Table 2. Comparison of calibration and validation statistics

The model has been driven by GDP and population forecasts carried out by the Bank of Thailand as far as the year 2016. Figure 8 shows this as well as a 2002 forecast by EGAT. While it clearly produces a lower growth in demand over the period than EGAT's the forecast is believed to be reasonable as different (and unknown) economic assumptions were used in the EGAT forecast.

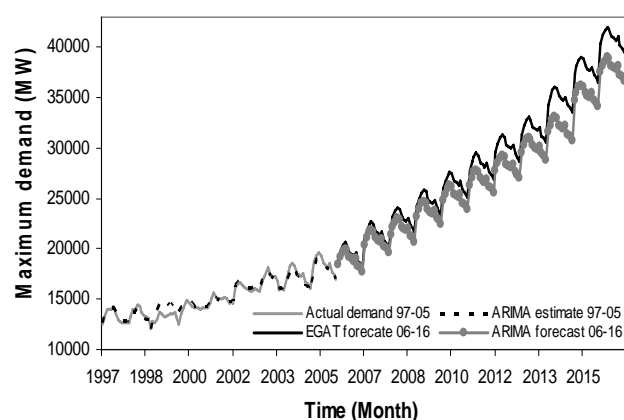


Figure 8. Historic and forecast demand in Thailand

Using this and the previous sensitivity information it is possible make an estimate of the impact a 1°C uniform rise would have on the peak demand in March, June and November 2016. Taking the monthly peak demand projected by the long-term model multiplying it by the percentage change in peak demand suggested by the hourly time-slice models presented in Table 1 it is possible estimate the increase a 1°C would have. Table 3 shows these results.

	MW demand per long-term model	MW increase per sensitivity model
March	38600	4100
June	38100	950
November	37050	820

Table 3. Projected impact of 1°C rise on 2016 demand

With the doubling of demand levels over the period to 2016, the 10.6% climate-related increase in peak demand represents over 4 GW of additional demand that is not forecast by the traditional long-term model based on the economic criteria. In any power system this is a significant additional generation requirement and lends support to the view that additional research is carried out to refine the climate-demand projections.

This approach has the benefit of simplicity but relies heavily on the relationships between temperature and demand levels holding into the future.

4 CONCLUSION

As part of a study into the potential impact of climate change on Thailand's electricity demand it has been necessary to find an efficient and effective way of linking climate to demand levels whilst minimising data requirements. The paper sets out a multiple linear regression approach to modelling the influence of temperature on demand by representing demand as hourly time-slices for each month across the year. The application of the models in determining the impact of uniform rises in temperature are presented along with a preliminary exploration of what such sensitivity means in terms of Thailand's demand levels in the second quarter of the century.

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